Definition of Requirements and Functions for SMART Tolling System

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ABSTRACT

This paper demonstrates the requirement of smart tolling systems for smart highway. In smart highway operators and drivers would be able to see in real time the information of traffic. The smart highway is next generation road aimed at Congestion Free, Stop Free and Accident Free through traffic information services. This study defines requirements and functions for development of smart tolling system as a multilane free flow road charging systems. The smart tolling systems support toll collect, no overloaded vehicles, speed enforcements and so on base on wireless communication systems.

1. INTRODUCTION

The smart tolling systems guarantee traffic free flow of smart highway, which it can charge the toll fare through one device with several toll fare policies.

Because the smart tolling systems is no restriction about the lane changing or passing another car ahead at charging point of time, it is occurred in communication and enforcement problems. When there are a lot of cars, communication systems must finish toll charging procedures before cars leave the detection zone. Therefore RES(Road Side System) and OBU(On board Unit) guarantee stability and satisfactory process speed of communication. For this, the smart tolling systems can be multi-connection and multi-toll collect system. Enforcement problems are occurred to difficult to know the location that the vehicles fail toll charging and without OBU.

To solve these problems, this study has considered followings.

- To ensure satisfactory detection zone for multilane free flow vehicles

- To ensure stability for communication and toll collection
- To ensure functions that can be vehicle detection and classification
- To detect location of vehicles that finish toll charging
- To recognize vehicles without OBU and non-payment vehicles

2. CURRENT STATUS OF RELATED STUDIES

2.1. Odometer Tolling

Odometer tolling promises to be an innovative method of electronic tolling. Odometer tolling involves use of an on-board mileage-counting unit to track and record total miles traveled by the vehicle. Tolls are calculated at a fixed fee per mile traveled by the vehicle. This method of user charging does not collect, record or store any private information associated with the vehicle or the user. The on-board unit only counts number of kilometers/miles commuted by the vehicle in a particular zone and cannot record the location or time of travel. The vehicle is also installed with a GPS unit that directs the on board mileage-counting unit whether to record number of miles as in state or outside state to prevent users being charged under the program when driving in other states.

2.2. Mobile phone Tolling

Mobile phone tolling offers another novel concept for electronic tolling. The concept involves installing a chip (similar to a mobile phone chip) in the vehicle to regularly communicate with cell towards while the vehicle is on the move and measure total distance traveled, which forms the basis for toll calculation. Mobile phone tolling involves lesser capital expenditure than GPS-based tolling as the basic infrastructure is already in place, which also makes the concept more technically feasible.

2.3. Satellite-based Tolling

Satellite-based tolling makes use of satellite systems to precisely track location of a vehicle, determine total distance traveled, and employ mobile communication systems to calculate tolls. An on-board unit (OBU) is installed on the vehicle, which establishes communication with satellites and periodically obtains data relate to the vehicle's location coordinates to track vehicle movements. Satellite-based tolling is likely to be the most deployed technology for distance-based electronic tolling in future as it is highly precise and reliable. Satellite tolling is expected to receive a major boost with introduction of the European Galileo Satellite system for Global Positioning.

2.4. Dedicated Short Range Communication based ETC Systems

DSRC, a short to mid-range wireless protocol, has been designed especially for use in automotives. Dedicated Short Range Communication (DSRC) based ETC systems make use of two-way DSRC communication frequency between in-vehicle devices known as transponders/tags/on-board units, and roadside infrastructure, which mainly includes transceivers.

In-vehicle transponders are mounted on the vehicle's windshield that aid in vehicle identification. Transceivers, which are mounted atop an overhead gantry either on the roadside or above motorways, determine the entry and exit limits of the concerned tolling zone. In addition to transceivers, roadside equipment also comprises of local computing infrastructure that aids in storing and transmitting data.

Roadside equipment transmits signals when the transponder-equipped vehicle passes through the tolling zone. Tolling data is then transmitted from the transponder to the transceiver, which is processed at the roadside computer and eventually transmitted to a central system through a data center, using Wide Area Network (WAN).

2.5. Automatic Number Plate Recognition-based ETC Systems

Automatic Number Plate Recognition (ANPR) - based ETC system comprises of mobile cameras and a pair of fixed cameras, which are positioned at select locations across the boundaries of the congestion zone. Cameras are incorporated with ANPR software, which enables accurate recognition and interpretation of images. Data acquired through cameras is transmitted to a processing center, where a comparison between number plates and a database comprising details of vehicle owners is made, and eventually payment data is processed.

2.6. A Comparison of DSRC and GPS based ETC Systems

The technology used in toll collection witnessed a gradual evolution. From manual toll collection during the 1990s, technology evolved to electronic toll collection (both infrared and DSRC – based). Currently, the most prevalent technology used in toll collection is DSRC microwave technology. However, the era of satellite-based tolling has dawned and the technology, despite a few snags, is emerging as the technology of the future.

DSRC and VPS systems are the most widely used systems in electronic toll collection. The relative superiority of one technology comes forth from end user requirements, especially pertaining to class and number of vehicles that are subject for tolling and the road network structure. In terms of cost, commissioning of VPS system is relatively inexpensive, as it requires lower roadside infrastructure (includes tolling system, central system, and enforcement system). However, costs of commissioning and operating enforcement and ventral systems do not vary much in both technologies.

DSRC systems hold competitive advantages over VPS systems in urban environs and on highways. Flexibility and cost benefits of DSRC systems are more profound in cases where tolling system is expanded to include other vehicle classes, for instance, expansion of the system, which currently includes trucks to also include cars. On the other hand, VPS systems hold cost and flexibility advantages in cases where toll-road network is expanded, including addition of other types of roads for tolling. It is for this reason that a combination of both technologies may prove to be a superior solution.

Yet another measure to assess relative superiority is the accuracy and reliability measure, which puts DSRC system in the lead. The measure of accuracy and reliability of ETC systems indicate the

actual number of transactions compared to potential transactions, which is reflected in toll revenues generated. Based on this measure, DSRC systems fare well over VPS systems and have delivered higher toll transactions than VPS systems. Lower rates achieved through VPS systems are primarily attributed to reasons such as variation in positioning data, (which may arise due to visibility of the vehicle to the satellite, general inaccuracies in positioning data and signal quality), and variation in the algorithm and map quality that invariably affects the accurate matching of positioning data.

3. Deciding basic direction on the development of Smart Tolling System Technology

This task examines requirements for constructing high-speed travelling (120km/h) Smart Tolling System based on multi-lane, non-stop for performing a series of procedures such as entering and exit of vehicles, collecting toll fees, managing violations in terms of operating Smart Highway. The aim of Smart Highway is providing timeliness, safety, efficiency and the sales methods should be designed to comply with these. Thus, the basic requirements are decided in three items accordingly.

First, vehicles should not reduce their speeds for paying fees under any circumstances in terms of providing timeliness. The High Pass System operated currently in a single lane method was aimed for non stop travelling but it disturbs flow of traffics since the speed should be reduced at around 30km/h on toll collection sections. Therefore, the Smart Tolling System to be newly adopted should provide environments where the speed of travelling vehicles is not reduced for paying tolls by constructing based on multi-lane system (MLFF, Multi Lane Free Flow).

Second, the components of toll collection system should be installed on gantry structure in terms of providing safety. The current High Pass System has installed various detection sensors for detecting vehicles on road surfaces and road sides classified as islands. These detection sensors require regular maintenances and replacements since they use contact system or optical system and corresponding lanes have to be closed every time for maintenance. It may cause serious safety issues if some of lanes are closed and conducting maintenances in multi-lane operation. Therefore, all the components of the Smart Tolling System should eliminate any possible circumstances such as sudden stops or sudden lane changes by installing the components on top of gantry structures.

Third, it should target all vehicles in terms of providing efficiency. That is, it should accommodate all existing DSRC Communication based High Pass terminals and vehicles without terminals.

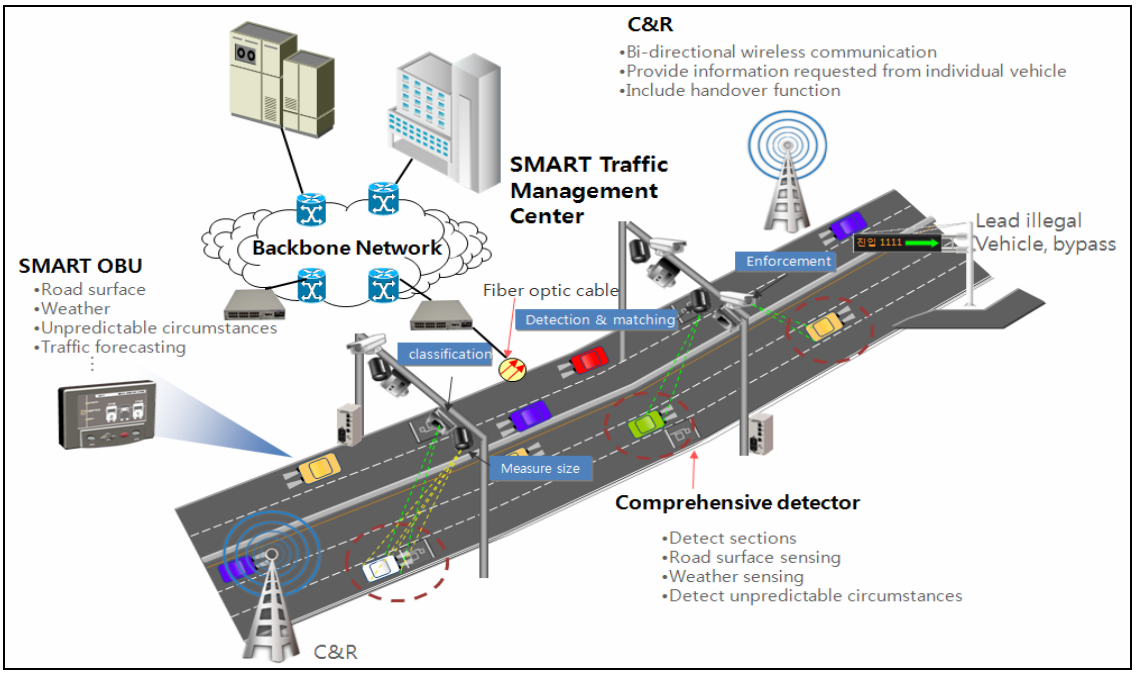


Figure1. Concept of the Smart Tolling System

The system is to be composed in the methods shown in the picture accounting for those 3 basic requirements and changes in current ETCS technologies and the basic plans for that are as in the following ways.

3.1. Mandatory entrance of vehicles with terminal

The Smart Tolling System is for guaranteeing Free Flow of traffics thus the entrance of vehicles with terminal should be mandatory to avoid creating stops or delays for paying tolls.

3.2. Multi Lane Free Flow

Site system should be composed by installing non-contact structure such as gantry on roads at the point of collection without separate toll collections (manual) to implement multi lane free flow collection. The composition of site system will differ according to lane composition, permissible range on the speed of travelling vehicles, vehicle classification system, composition of violation detection system and individual items for consideration are as follows.

3.2.1. Multi Lane System

The current High Pass System is a single lane toll collection system and single lane system requires regular maintenance since there are many structures constructed on roadsides and it recommends travelling speed of 30km/h with reasons of acquiring travelling safety and detecting violations thus it is a system difficult to guarantee free flow.

Multi lane system is essential in the Smart Tolling System since it is for making the flow of traffic smooth. There needs analysis and verification on system performance requirements on communication technologies, vehicle matching technologies, automatic toll collection technologies to

introduce multi lane system. The infrastructure should have accuracy and reliability at over 99% to guarantee correct decisions on prices and charging accurate toll fees when collecting tolls.

3.2.2. Vehicle travelling speed

The travelling speed at Smart Highway is based on 120km/h but allowable maximum vehicle speed is set at 200km/h (detection speed). This is reflecting a similar rate by taking into account the base for High Pass system performance is 160km/h at maximum when the vehicle speed is based on 100~110km/h when constructing highways, and it was set to collect tolls from vehicle travelling at the speed of 1.5~1.6 time of the standard on highway construction.

3.2.3. Vehicle Classification System

Vehicle classification system is currently composed of underground detection system such as loop or treadle. There requires maintenance system that does not obstruct flow of traffic at high speed for Smart Highway thus non-underground vehicle classification system should be considered such as classification by sensors, classification by terminal input information, classification by video from camera. However, non-underground system is difficult to be classified into 6 standards on classification (number of axis, tread, width) of the current Korea Highway Corporation thus semi-permanent vehicle classification system and methods of operations which can detect in high speed should be considered as well.

3.2.4. Violation Detection System Composition

It is a system for operating in multi lane and should be composed by linking with the above multi lane system, there needs review on plans for improving system accuracy.

3.2.5. Plans for paying fees on site

Direct payment methods where fees are paid at the time of passing collection point like OBU such as current High Pass System for collecting fees on site and prepaid methods meaning fees are deposited before entering the collection point by linking vehicle ID such as Tag with advance registration account in advance can be considered.

3.3. Linking with High Pass System

High Pass terminal users being currently operated by Highway Corporation are estimated to be about 2.2 million units (Feb 2009) and a plan to increase by 4 million by 2010 was established. Furthermore, current High Pass terminals are being upgraded and all-in-one navigations being launched at present. System should be reviewed to enable Smart Tolling through already supplied terminals.

3.4. Stable System Operation

Smart Tolling System can provide various advantages such as reduction in traffic congestion, reduction in fuel consumption, time saving but the system solely relies on computer technologies like wireless communication technology thus it may cause overall delays and problems in toll collections if

malfunctions even for a short period. It should be able to operate system stably to avoid causing the following problems.

- Inaccurate collection of toll fees
- Delay in settlement
- Double collection due to the presence of multiple communication system and terminals
- Damages on terminals

Comprehensive service counter system such as maintenance system for non-stop system operation, automatic processing when terminal malfunctions, sales environment response technologies such as automatic process on special vehicles, internet mobile portal for user convenience should be reviewed as well for stable operation of Smart Tolling System.

4. Deciding System Requirements

There is no restriction on driving within the range stipulated by Road Traffic Act on multilane of Smart Tolling thus there is no restriction on overtaking or lane changes at the point of collection. Therefore, there could be problems in communication between devices in car and road side devices and detecting violations due to characteristics of vehicle travelling on multilane.

Communication problems should presume stable communication connection between receivers and devices in car and sufficient processing time since required communication procedures should be completed before the vehicles drive out of detection area in the order of detection if there are many vehicles in vehicle detection area. The communication area and detection area of Smart Tolling System should implement a system enabling multiple connections and processing of multiple collections by designing according to the characteristics of multilane roads.

The following problems should be considered to efficiently operate automatic collection system under multilane environment since there could be problems in detecting violations if the location of vehicle without terminals and vehicles failing to pay fees can not be identified in Smart Tolling System.

4.1. Utilize short-haul communication technology

The given time for communication is short due to the characteristics of short-haul communication thus very stable communication environment should be provided to enable normal electronic collection from all vehicles within communication area and at the same time should ensure sufficient detection area for detecting vehicles travelling in high speed. It is requested to detect all vehicles travelling communication area and identifying the types of vehicle. It should be able to identify the location of vehicles completing normal collections and should continuously track within communication area.

4.2. Utilize broadband communication technology

It is possible to solve the problems of system using short-haul communication technology as shown above but it should solve problems in priority such as on error caused by GPS reception error,

identifying highway and nearby roads since the radius of communication is wide for CDMA mobile communication.

4.3. Utilize image recognition technology

The rate of recognition is low at around 98% (automatic recognition 95%+eye detection rate 3%, based on London System) for ANPR System and recognition rate is expected to be lower in Korea where non-reflective number plates are mixed thus it is believed to be highly inefficient in terms of cost if the number of vehicles increases.

4.3.1. Smart Tolling Operable System

The major contenders for Smart Tolling System based on analysis on national international cases and basic requirements are shown below.

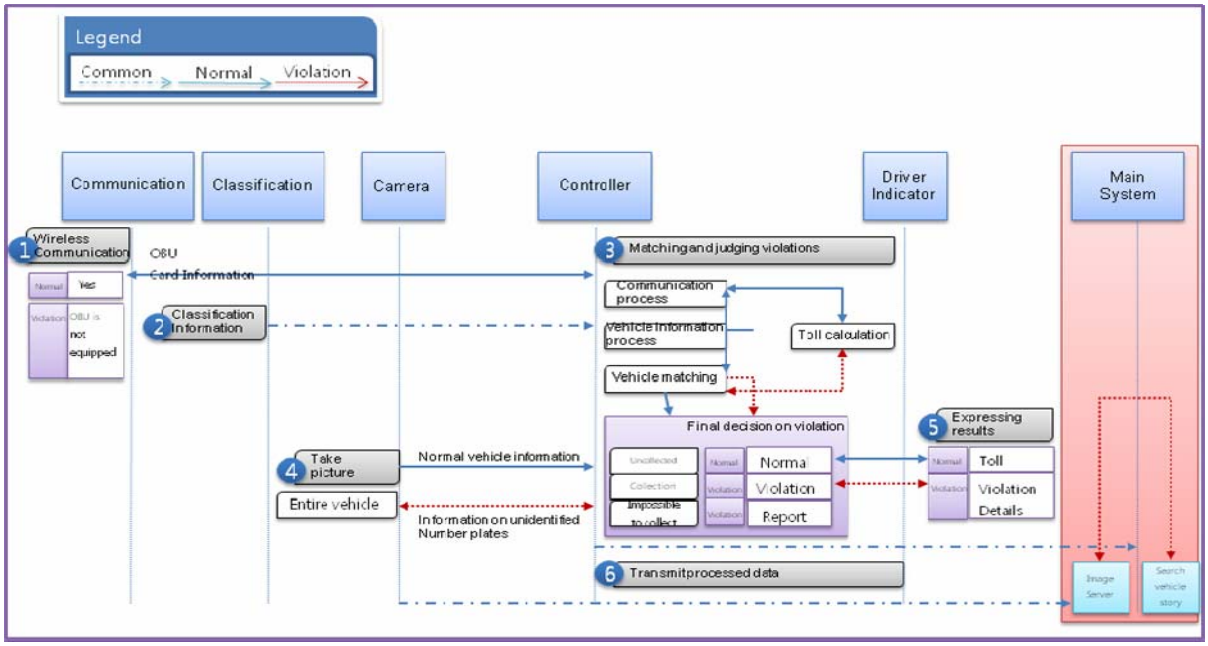
Table 1. Major contenders for Smart Tolling System

Item	Upper Class	Middle Class	Advantages
Communication Methods	Wireless Communication	Tag	· Low priced terminal · Low reliability (impossible to process high speeding vehicles)
		DSRC Communication	· High communication reliability · Possible to accommodate already supplied High Pass terminals
		GPS/CDMA Communication	· Low priced system · Low reliability (Radio wave shade area, low resolution)
	Non-wireless Communication	ANPR	· Does not need to supply terminals · High system operation costs
Vehicle Classification	Contact sensors	Electronic mechanic	Inaccurate at above 90km/h
		piezoelectricity	Inaccurate at below 8km/h
		Optical	High accuracy. Inappropriate in multilane environments
		Resistance tester	Inaccurate at above 130km/h
	Noncontact sensors	Laser scan	Requires regular maintenance on driving gear
		Infrared scan	2-dimensional detection. Impossible to measure vehicle length
		Ultrasound scan	Accuracy drops according to surroundings
		Video image	Continuous scanning and detection is possible
		Optical beam and optical curtain	· Use multiple optical beam in horizontal direction · Inappropriate in multilane environments
Evasion Prevention	Image	ANPR	Take images of front or back

5. Plans on Smart Tolling System Composition

5.1. Defining Smart Tolling System Scenario and Fee Collection Flowchart

5.1.1. System Processing Procedures



Communication information	· Record communication information on electric card and OBU by communicating with OBU when vehicle with Smart Tolling enters into communication area
Vehicle class information	· Vehicle classification device transmits vehicle class to comprehensive lane controller when vehicles pass
Matching and judging violation	· Make final decision on violation after matching communication information and vehicle class · Process as violation of OBU when there is no communication information for a certain period after receiving vehicle class information · Violation on abnormalities in taking pictures (unrecognizing number plates)
Take picture of violating vehicles	· After taking pictures of entire vehicles · transmit images of violating vehicles if applicable to image server from device taking picture of violations · Delete images if not violating
Express results	· Express fees if normal and reason for violation on driver indicator (OBU or facility)
Transmit processed data	· Transmit comprehensive processed data on one vehicle to lane controller and the final data is transmitted to main server of office · Does not process separation violation from the entrance · Process as violation from center after going through examination on violation for exit

Figure2. Process of the Smart Tolling System

5.1.2. Defining Smart Tolling Service Scenario

Smart Tolling Service enables to pay non-stop, multi lane tolls in highways using wireless communication (between ASE and OBU) inside a travailing vehicle. This service enables to paying

fees nonstop and in multi lane by automating the payment of highway tolls and reduces delays in paying tolls thus reduce driver inconvenience and pollution thus expect to improve traffic environments. Data flowchart for providing service is shown below.

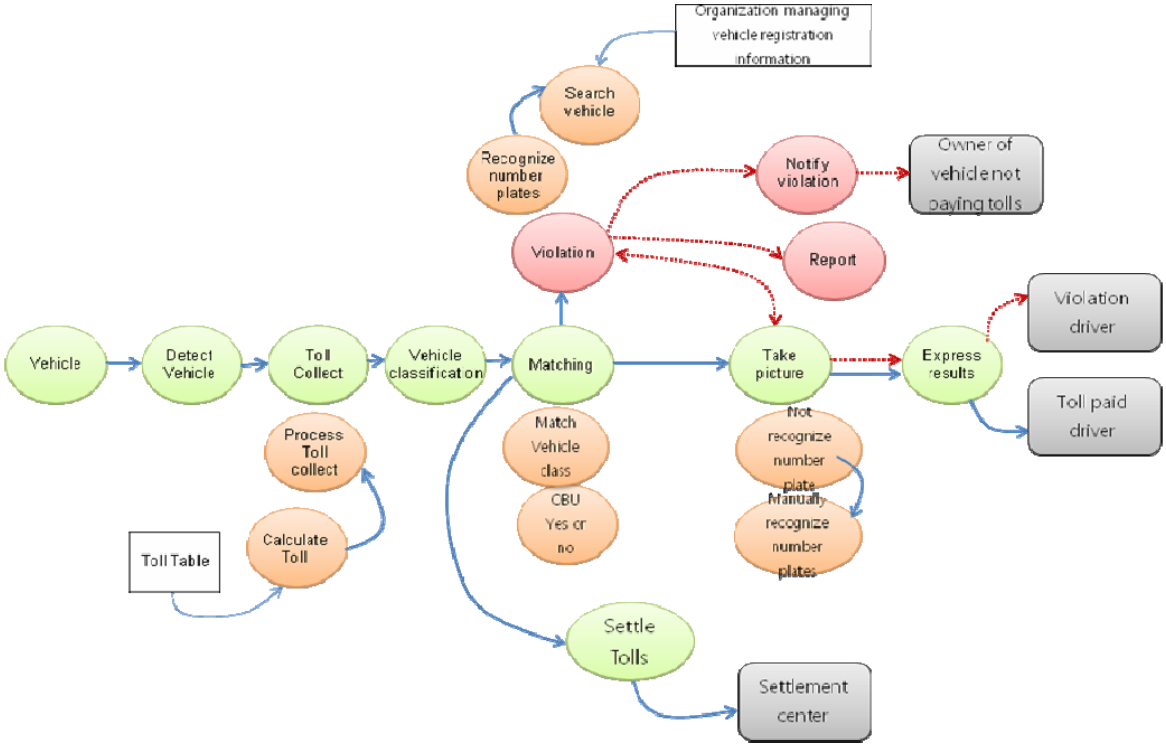


Figure3. Data flow of the Smart Tolling Service

5.2. Smart Tolling System Requirements

Smart Tolling System was reviewed based on existing DSAC Communication, there are international cases for RF tag and GPS/CDMA methods but the reliability on charging fees according to the speed of travelling vehicle drops and thus need to introduce a separate communication technology to compliment this.

The data transmission speed of DSRC Communication is high at 1Mbps and provide highly stable wireless communication environment. Also, it is believed to be possible to expand to multilane since the setting of communication area is free. However, the number of channels being used is limited thus design of Multilane Cooperative System is essential to prevent interference between vehicles, and requires complementation through parallel multi SAM for reducing processing time.

The reliability on vehicle classification technology drops at speed over 120km/h under road surface sensor methods being used in current High Pass and it is difficult to compose unless single lane environment. Therefore, noncontact methods such as laser scanning or video recording methods should be introduced whose durability is semi-permanent and no restriction on detection range.

However, it is necessary to introduce new classification system that detecting exterior of vehicle (length, width, height) unlike existing vehicle classification system.

It is appropriate to consider a method of taking picture of front and back at the same time to target multilane, multi vehicles for evasion prevention technology and it would be appropriate to consider duplication, real-time linking, shadow prevention as well.

The following should be considered for automatic tolling technology. Current High Pass toll collection process is composed of 3 steps of initialization, procedure of collecting tolls, post-processes and initialization period (130ms) and procedure on toll collection (130ms) that actually require real-time bidirectional wireless communication should be more than 260msec. The size of communication area should be at least 14m to ensure time (260ms) for processing toll collection since vehicles travel at 55m/sec if speed is 200km/h in Smart Tolling System. However, it is expected to secure more than 16~18m for communication area when considering retry of DSAC communication, considering the process of dividing multi entering OBU, composition of cooperative system for OBU tracking and improvements on system processing ability should be conducted at the same time.

The time for processing for current High Pass System is spent mostly in SAM which is smart card or direct linking thus it is expected to process vehicles travelling at the speed of 200km/h in multilane environments if times in those areas can be reduced.

Items to be considered on Smart Tolling System against existing High Pass System are shown below.

Table 2. Requirements of Smart tolling systems

Wireless communications	Vehicle matching	Automatic a fare payment	Vehicle a classification
- Communications speed : 1Mbps~ - Control of communications zone -Percentage of error in communications: 0.1% - Multi lane operation - Transit speed : over 200km/h	- Necessity of vehicle trajectory - Grasp of communications beginning time of point - Multi antenna	- Tag+OBU - Several toll charge - SAM process speed : under 10ms - Check the B/L(black list), W/L(White list)	- Vehicle shape x/y/z detection - Detection speed : over 200km/h - Durability semi-permanent - No detection range

Enforcement prevention	Maintenance System	User service system
- Multi lane operation : wide seeing & angle camera, image lane analysis - Percentage of interpretation a number plate : over 95% - Operation & plan : dual processor , real time connection, shadow protection, continuous photographing	- Non-stop system operation through system dual processor - Network & system real time monitoring - Portable gantry	- Establishment of internet, portal site .general /a business .a device issue/refund .charge / refund of tag and card - Establishment of mobile portal site - Construction of call-center - Installation of kiosk - Account service etc

6. CONCLUSION

Smart tolling systems can be bringing in a massive change in the present pay toll collection methods, enabling significant time and cost savings and increased convenience for commuters while simultaneously generating greater revenues for operating agencies. These systems are expected to offer high level of standardization and compatibility with other types of intelligent transportation systems, resulting in improved operational efficiency and interoperability.

Tags mounted on vehicles as part of ETC systems can be potentially employed to augment current transportation system, bringing appreciable gains to customers and administrative agencies alike. Tags can be programmed to store a variety of information including driver's license and identity, and various provincial, state, and federal government guidelines for operating a commercial vehicle. This would improve security and enable easy roadside inspection, apart from minimizing administrative workload of government agencies. Smart tolling systems can also furnish valuable data related to traffic flow, traffic information and management support systems for further streamlining.

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